

B_c photoproduction at HERA collider*

A.V.Berezhnoy [†] A.K.Likhoded [‡]

Abstract

The B_c photoproduction at HERA has been considered in the frame work of the pQCD. The estimated value of the total production cross section of B_c^+ , B_c^{*+} , B_c^- and B_c^{*-} mesons is about 5 pb. Higher excitations yield about 30% to the total cross section. Thus for integrated HERA luminosity 1 fb^{-1} about $7 \cdot 10^3$ B_c mesons will be produced.

1 Calculation technique

The main features of the ep -production of B_c in the frame work of pQCD had been discussed in our previous work[1]. The dominant subprocess $\gamma g \rightarrow B_c + X$ is described by 24 Feynman diagrams. We suppose that the amplitude of the production process can be expressed through the amplitude T of hard production of four heavy quarks $b\bar{b}c\bar{c}$ followed by the soft fusion of \bar{b} and c quarks into B_c meson due to the meson wave function Ψ :

$$A_{\gamma g \rightarrow B_c + b + \bar{c}} \sim \int T_{\gamma g \rightarrow b\bar{b}c\bar{c}}^{\text{hard}}(p_i, \vec{q}) \cdot \tilde{\Psi}_q^*(\vec{q}) d^3q,$$

where p_i are four momenta of B_c , b and \bar{c} ; \vec{q} is the three momentum of \bar{b} quark in the B_c meson rest frame.

One can neglect the \vec{q} dependence in $T_{\gamma g \rightarrow b\bar{b}c\bar{c}}^{\text{hard}}$ and get for S wave states production the following equation:

$$A_{\gamma g \rightarrow B_c + b + \bar{c}} \sim \Psi(0) \cdot T_{\gamma g \rightarrow b\bar{b}c\bar{c}}^{\text{hard}}(p_i, 0),$$

where $\Psi(0)$ is the value of B_c wave function value at origin (coordinate space).

In such approach \bar{b} and c quarks in B_c have the same velocities. Thus:

$$p_{\bar{b}} = \frac{m_b}{M_{B_c}} P_{B_c},$$

$$p_c = \frac{m_c}{M_{B_c}} P_{B_c}.$$

If one need to get the yields of B_c and B_c^* separately, the product of spinors $v_{\bar{b}}\bar{u}_c$, corresponding to the \bar{b} and c quarks in the $T_{\gamma g \rightarrow b\bar{b}c\bar{c}}^{\text{hard}}$ amplitude, should be substituted by the projection operator

$$\mathcal{P}(\Gamma) = \sqrt{M} \left(\frac{\frac{m_b}{M} \hat{P}_{B_c} - m_b}{2m_b} \right) \Gamma \left(\frac{\frac{m_c}{M} \hat{P}_{B_c} + m_c}{2m_c} \right),$$

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[†]Scobeltsyn Institute for Nuclear Physics of Moscow State University, Moscow, Russia.

[‡]Institute for High Energy Physics, Protvino, Russia.

where $\Gamma = \gamma^5$ for $s = 0$, or $\Gamma = \hat{\varepsilon}^*(P_{B_c}, s_z)$ for $s = 1$, where $\varepsilon(P_{B_c}, s_z)$ is the polarization vector for the spin-triplet state.

Nevertheless, one can easily show that Γ can be expressed through the v_b and \bar{u}_c :

$$\mathcal{P}(\gamma^5) = \sqrt{\frac{2M}{2m_b 2m_c}} \frac{1}{\sqrt{2}} \{v_b(p_b, +)\bar{u}_c(p_c, +) - v_b(p_b, -)\bar{u}_c(p_c, -)\},$$

$$\mathcal{P}(\hat{\varepsilon}^*(P_{B_c}, -1)) = \sqrt{\frac{2M_{B_c}}{2m_b 2m_c}} v_b(p_b, +)\bar{u}_c(p_c, -),$$

$$\mathcal{P}(\hat{\varepsilon}^*(P_{B_c}, 0)) = \sqrt{\frac{2M_{B_c}}{2m_b 2m_c}} \frac{1}{\sqrt{2}} \{v_b(p_b, +)\bar{u}'_c(p_c, +) + v_b(p_b, -)\bar{u}_c(p_c, -)\},$$

$$\mathcal{P}(\hat{\varepsilon}^*(P_{B_c}, +1)) = \sqrt{\frac{2M_{B_c}}{2m_b 2m_c}} v_b(p_b, -)\bar{u}_c(p_c, +).$$

The more detailed description of the calculation technique one can find in the papers [2], where the gluonic and photonic B_c production cross sections had been calculated (see also [3]).

To get the cross section of B_c production in ep collision one should convert the cross section of the subprocess $\gamma g \rightarrow B_c + X$ with the distribution function of gluon in the initial proton (we use CTEQ6 parametrization of PDF [4]) and Weizsäcker-Williams photon function.

2 Results

The parameter values have been chosen as follows:

$$\alpha_s = 0.2,$$

$$m_c = 1.5 \text{ GeV},$$

$$m_b = 4.8 \text{ GeV}$$

$$|\Psi(0)|^2 = 0.116 \text{ GeV}^3.$$

The total production cross section of B_c^+ , B_c^{*+} , B_c^- and B_c^{*-} mesons is about 5 pb. Higher excitations yield about 30% to the total cross section. Thus for integrated HERA luminosity 1 fb^{-1} about $7 \cdot 10^3$ B_c mesons will be produced. It is rather small amount of B_c to find these particles at HERA, because of small branching ratios of B_c decay mode, which are interesting for the extraction of B_c signal. Nevertheless, one can hope to find these particles at HERA collider.

3 Remarks

The most popular model of B meson production is the fragmentation one. In accordance to this mechanism at large $p_T > p_T^f$ quark b quark is produced in the hard process followed by the soft process of heavy quark fragmentation. For example: $\gamma g \rightarrow b\bar{b}$ followed by $b \rightarrow B$. The meson production cross section in the frame work of fragmentational model have a very simple form:

$$\frac{d\sigma(\gamma g \rightarrow B + X)}{dz} = \sigma(\bar{b}b) \cdot D_{b \rightarrow B}(z),$$

Table 1: The branching ratios of exclusive B_c decay modes [5].

B_c decay mode	BR, %	B_c decay mode	BR, %
$\psi l^+ \nu_l$	2.5	$\eta_c l^+ \nu_l$	1.2
$B_s^* l^+ \nu_l$	6.2	$B_s l^+ \nu_l$	3.9
$\psi \pi^+$	0.2	$\eta_c \pi^+$	0.2
$B_s^* \pi^+$	5.2	$B_s \pi^+$	5.5
$\psi \rho^+$	0.6	$\eta_c \rho^+$	0.5
$B_s^* \rho^+$	22.9	$B_s \rho^+$	11.8

where $z = 2E_{B_c}/\sqrt{s_{\gamma g}}$.

But can we estimate the numerical value "large" p_T^f ?

For B_c production we can do it in the frame of model discussed in Chapter 1 and 2 of this paper:

$$p_T^f \sim 30 \text{ GeV} \sim 5M_{B_c}$$

At $p_T < 5M_{B_c}$ nonfragmentational terms (recombination terms) give the dominant contribution into B_c production cross section.

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References

- [1] A.V. Berezhnoy, V.V. Kiselev, A.K. Likhoded, *Phys. Atom. Nucl.* **61**, 252 (1998); *Yad. Fiz.* **61**, 302 (1998), Preprint DESY-97-193.
- [2] A.V. Berezhnoi, A.K. Likhoded, M.V. Shevlyagin, *Phys. Atom. Nucl.* **58**, 672 (1995); *Phys. Lett.* **B342**, 351 (1995); A.V. Berezhnoy, V.V. Kiselev, A.K. Likhoded, *Phys. Lett.* **B381**, 341 (1996), *Z. Phys.* **A356**, 79 (1996), *Z. Phys.* **A356**, 89 (1996).
- [3] S.P. Baranov, *Phys. Rev.* **D56**, 3046 (1997); K. Kołodziej, A. Leike and Rückl, *Phys. Lett.* **B355**, 377 (1995); C.-H. Chang, Y.-Q. Chen, G.-P. Han and H.-T. Jiang, *Phys. Lett.* **B364**, 78 (1995); C.-H. Chang, Y.-Q. Chen and R.J. Oakes, *Phys. Rev.* **D48**, 4344 (1996); C.-H. Chang, Y.-Q. Chen, *Phys. Rev.* **D48**, 4086 (1993).
- [4] J. Pumplin, D.R. Stump, J. Huston, H.L. Lai, P. Nadolsky, W.K. Tung, *JHEP* **0207**, 012 (2002), D. Stump, J. Huston, J. Pumplin, W.K. Tung, H.L. Lai, S. Kuhlmann, J. Owens, *JHEP* **0310**, 046 (2003).
- [5] S.S. Gershtein, V.V. Kiselev, A.K. Likhoded, A.V. Tkabladze, A.I. Onishchenko, A.V. Berezhnoy *The talk given at IV Workshop on Progress in Heavy Quark Physics*, Rostock, September 20-22, 1997.

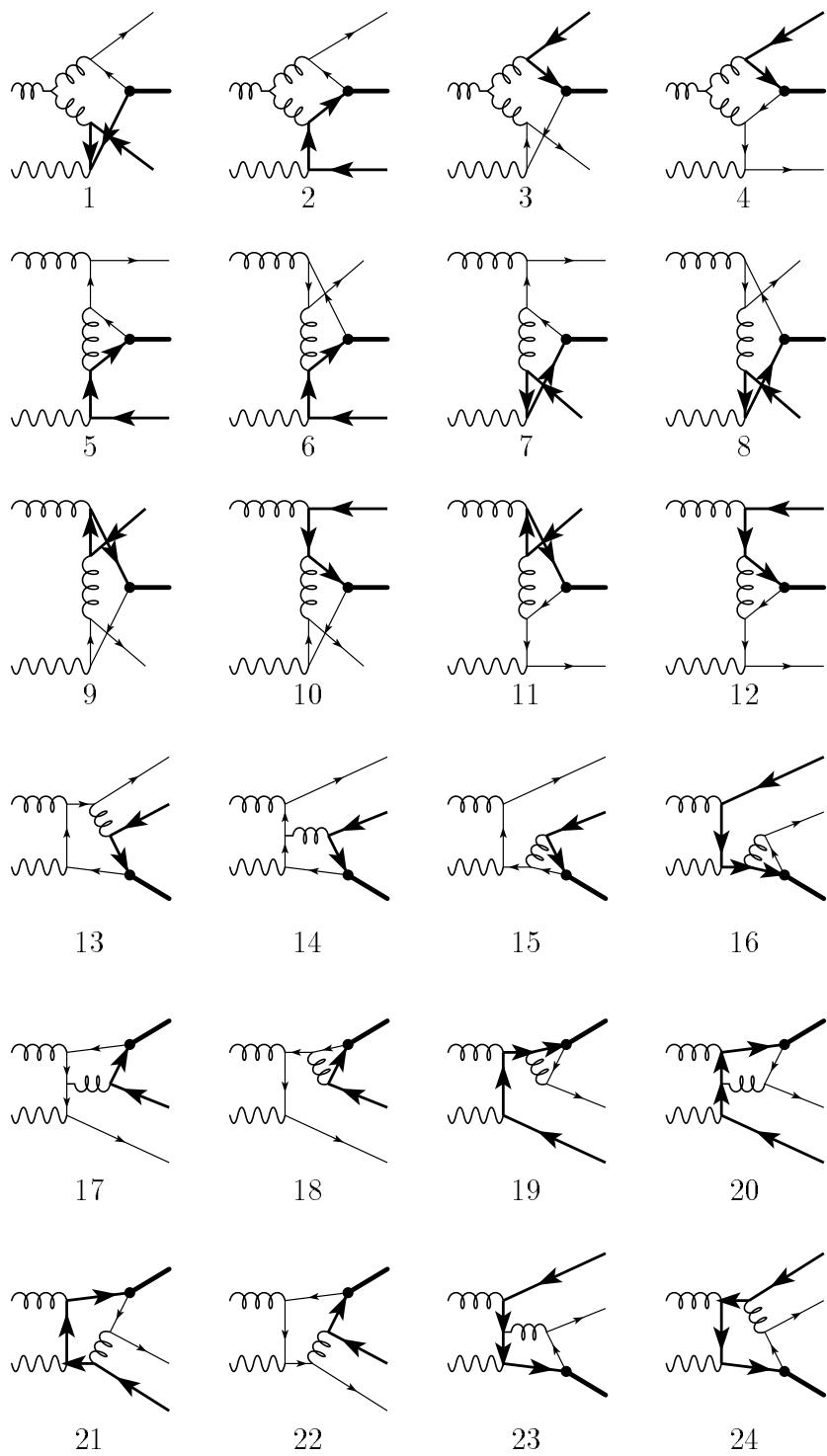


Figure 1: Feynman diagrams for the process $\gamma g \rightarrow B_c + X$

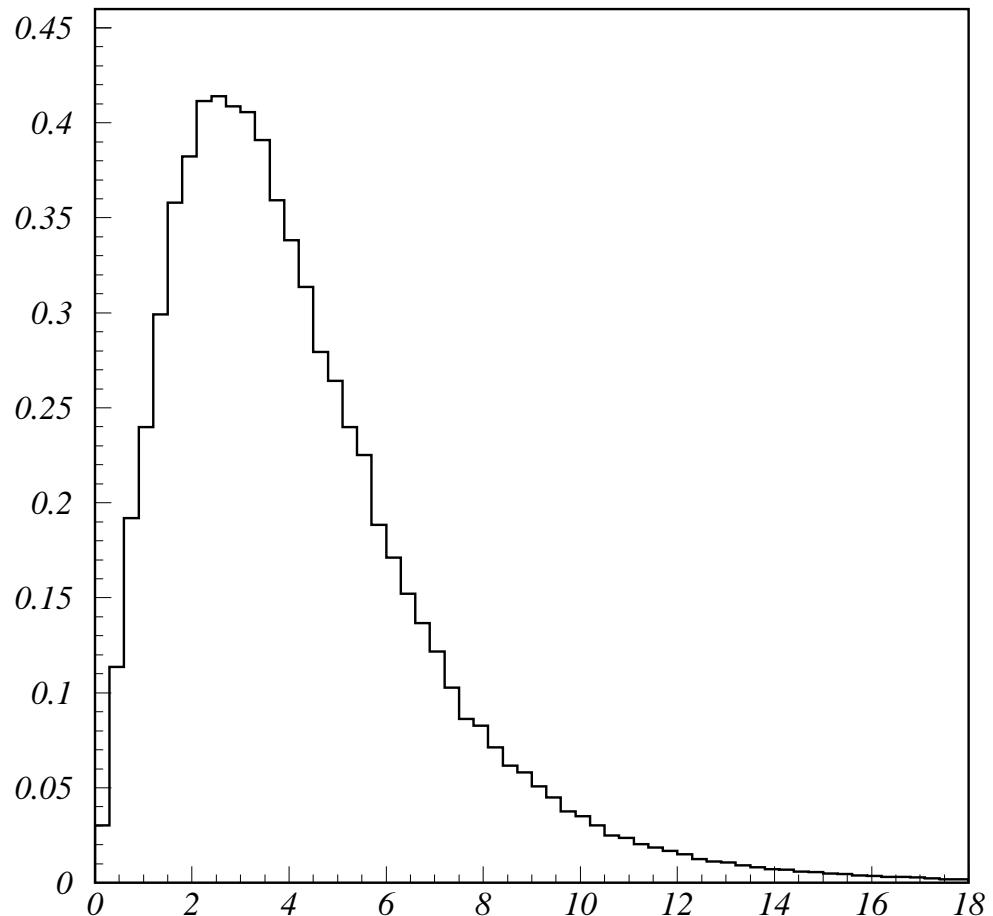
$$\frac{d\sigma_{B_c}}{p_T}, \text{ pb/GeV}$$

$$p_T, \text{ GeV}$$

Figure 2: The cross section distributions on p_T for B_c photoproduction at HERA

$$\frac{d\sigma_{B_c}}{d\eta}, \text{ pb}$$

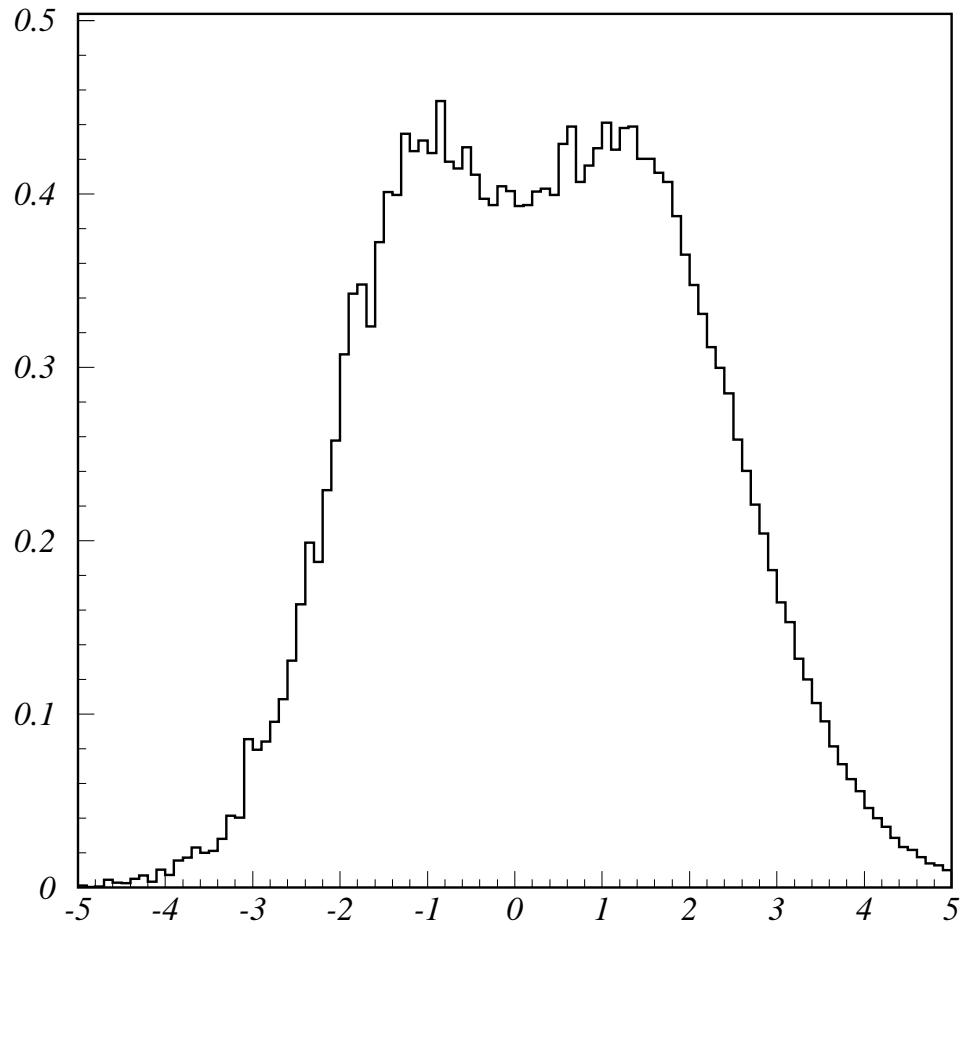
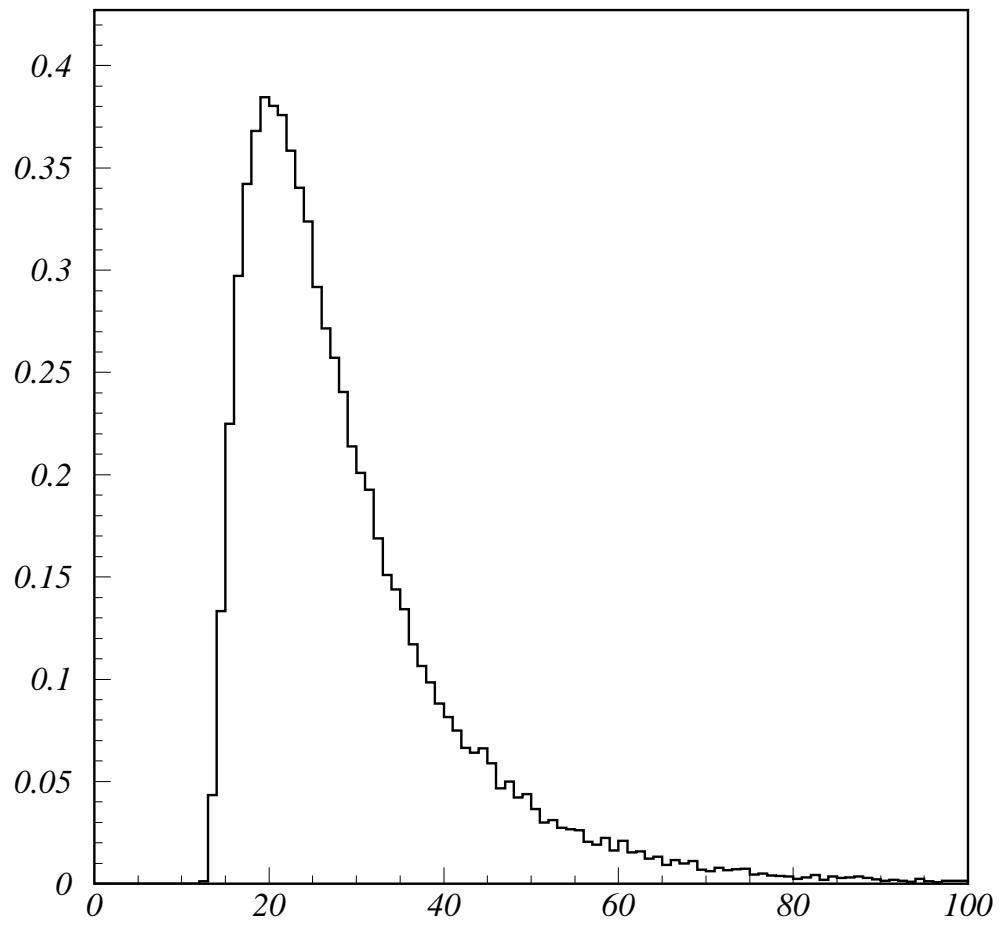


Figure 3: The cross section distributions on η for B_c photoproduction at HERA

$$\frac{d\sigma_{B_c}}{d\hat{s}_{\gamma g}}, \text{ pb}$$



$$\hat{s}_{\gamma g}$$

Figure 4: The cross section distribution on $\hat{s}_{\gamma g}$ for B_c photoproduction at HERA